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Peeyush Varshney
Iowa State University

Rameshwar S. Kanwar
Iowa State University, rskanwar@iastate.edu

James L. Baker
Iowa State University, jlbaker@iastate.edu

Carl E. Anderson
Iowa State University

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P. Varshney, R. S. Kanwar, J. L. Baker, C. E. Anderson
Student Member ASAE, Member ASAE, Member ASAE, Member ASAE

Abstract. *A field study was conducted on Nicollet loam soils to determine the effects of tillage and nitrogen (N) management on the residual nitrate-nitrogen (NO_3-N) in the soil profile. Two replications of two tillage systems (no-till and moldboard plow) and two N management practices (single application of N at the rate of 175 kg/ha and three applications totaling 125 kg/ha) were used for continuous-corn production. Soil samples were taken periodically each year to a depth of 150 cm at three locations within each of the six experimental plots (9 m apart, one along and two on either side of a tile drain running down the center of the plot). No-till and three N applications with a lower total application rate reduced the residual NO_3-N in the soil profile. Regression analysis of the data showed less residual NO_3-N under no-till system having a definite decreasing trend with depth. Eight years (1984-1991) of data indicate that corn yields were not affected by tillage or N management practices.* **Keywords.** *Tillage, Nitrogen, Fertilizer, Nutrients, Management, Corn, Soil samples.*

Increased nitrate-nitrogen (NO_3-N) concentrations in tile drainage water and in deeper groundwater sources, as a result of higher application rates of nitrogen (N) fertilizer, have been documented in several studies (Baker and Johnson, 1981; Gast et al., 1978; Kanwar et al., 1988; Kanwar and Baker, 1991; Schepers et al., 1986). Tillage is one of the major agricultural activities affecting the transport of NO_3-N to groundwater. It directly affects soil water properties of the surface as well as subsurface soil and therefore leaching characteristics. Tillage disturbs the network of macropores thus potentially reducing preferential flow. Timing and rates of N-fertilizer applications can affect both the availability of N for crop growth and the amount of NO_3-N remaining in the soil profile (Gast et al., 1978; James, 1978; Jokela, 1992; Kanwar et al., 1985).

The amount and distribution of inorganic N, primarily NO_3-N, remaining in the soil profile at the end of the growing season (residual N) is greatly affected by fertilizer management as well as by the soil moisture regime. Application rates of N greater than those needed for optimum crop yields can cause an accumulation of large amounts of NO_3-N in the soil profile and, in some cases, movement beyond the root zone (Nelson and MacGregor, 1973; Jolley and Pierre, 1977; Olsen et al., 1970). In several studies in Nebraska, N application later in the season has consistently shown larger amounts of residual N and a greater proportion near the surface than application at planting time (Herron et al., 1971; Russelle et al., 1981; Johnston and Fowler, 1991). Residual N potentially available for the following year's crop is also susceptible to loss by leaching or denitrification. A field study in Wisconsin (Olsen et al., 1970) showed greater leaching of NO_3-N over the winter than during the growing season.

Herron et al. (1971) conducted field experiments to study the residual mineral N accumulation in soil and its utilization by irrigated corn. Delayed fertilizer application resulted in greater crop use efficiency and more residual N than with preplant application, suggesting greater losses through leaching and gaseous evolution with the preplant application in early spring months when there are no active crop roots for rapid uptake of N.

As part of this study, field experiments were conducted by Kanwar et al. (1988) to study the effects of no-till and conventional tillage, and single and multiple N applications, on the leaching of NO_3-N with subsurface drainage water below the root zone of continuous corn. Comparisons were made between conventional and no-till with a single N application of 175 kg/ha at the time of planting, and between a single application of 175 kg/ha and three N applications at a total of 125 kg/ha with the no-till system. No significant effects of tillage and N management were observed in the first year of the experiments. However, in the third year a significant reduction of NO_3-N in subsurface drainage water with no-till relative to conventional tillage was observed. Also with no-till, three N applications at a lower total rate reduced NO_3-N concentrations in drainage water compared with the single, higher rate of application.

Nyborg and Malhi (1989) conducted field experiments in north-central Alberta to compare the effect of no-till versus conventional tillage on soil NO_3-N content, soil water content, and soil temperature on two soils with two

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The authors are **Peeyush Varshney**, Graduate Research Assistant, **Rameshwar S. Kanwar**, Professor, **James L. Baker**, Professor, and **Carl E. Anderson**, Associate Professor, Dept. of Agricultural and Biosystems Engineering, Iowa State University, Ames.

Table 1. Date of planting, harvesting, and fertilizer application and plant populations

Item	Year and Date							
	1984	1985	1986	1987	1988	1989	1990	1991
Planting	14 May	2 May	7 May	1 May	6 May	10 May	2 May	9 May
Plant population count	11 Jun	29 May	29 May	1 / 2 Jun	—	25 May	27 May	5 Jun
Plant populations (plants / acre)	26,636	26,821	27,723	25,709	27,500*	25,140	26,140	22,600
N-application								
Single application (175 kg / ha)	23 May	2 May	20 May	15 May	20 May	15 May	9 May	10 May
Three applications (125 kg / ha)								
(25 kg / ha) 1st	23 May	17 May	8† Jun	15 May	20 May	31 May	8 May	20 May
(50 kg / ha) 2nd	26 Jun	5 Jun	25 Jun	16 Jun	3 Jun	3 Jun	27 Jun	6 Jun
(50 kg / ha) 3rd	3 Jul	24 Jun	15 Jul	1 Jul	23 Jun	6 Jul	19 Jul	26 Jun
Harvesting	2 Oct	11 Oct	21 Oct	6 Oct	6 Oct	26 Oct	17 Oct	2 Oct

* Planting rate, actual population estimated to be about 10% less.
† Rainfall prevented earlier application.

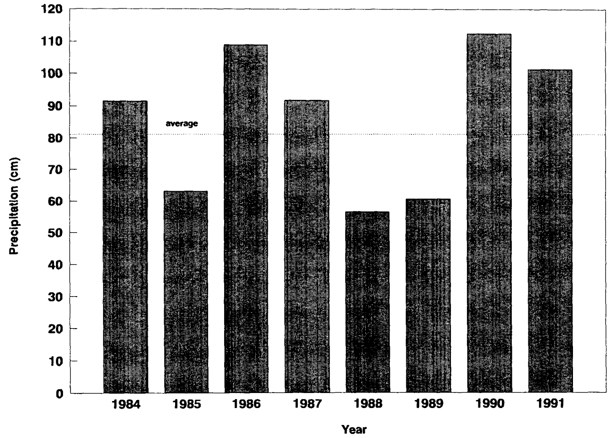

Figure 1–Annual precipitation for Ames (1984-1991); long-term average is 81 cm.

tillage treatments and two rates of applied N. The first crop did not show much of a response to applied N and yields were similar among treatments, but by the third crop, no-till plots without N produced significantly less yield than conventional tillage. However, yields on the no-till plots approached those of the conventional tilled plots when N was added. Since NO_3-N is subject to losses by denitrification and leaching, lower N mineralization rates under no tillage may reduce potential for NO_3-N loss. Timmons and Cruse (1990, 1991) in studies conducted in central Iowa found that, about one year after application, an average of 20% of the applied N remained in the soil profile and 95% of that was found in the organic N pool. Labeled N accumulation in corn grain was affected by fertilization method but not by tillage. Jokela and Randall (1989) found that residual NO_3-N in the fall was consistently increased by delayed application of the high N rate from the planting (PL) to eight-leaf (8L) stage, with most of the increase occurring in the upper 60 cm of the profile. In a similar study, Jokela (1992) found negligible effect of the time of N application on yield. Samples taken before planting and after harvesting from 1.5 m soil profile showed increases in soil NO_3-N that were related to the amounts of manure and fertilizer N applied.

Tracy et al. (1990) found that untilled soils accumulated more NO_3-N than plowed soils in the 0- to 5-cm layer. Tillage did not influence net N mineralization below the 5-cm soil depth. Varvel and Peterson (1990) found that high N application resulted in greater residual NO_3-N concentrations for continuous corn and continuous grain sorghum than for any other crop. Residual NO_3-N concentrations were low (< 4 mg/kg at depths below 30 cm) at all N application rates for continuous soybean and 2- and 4-year cropping systems. Considerable amounts of fertilizer N have been found in the soil organic N fraction. Kitur et al. (1984) reported that 28 to 42% of the fertilizer N applied to corn remained in the soil, depending on the N rate and tillage. The objective of this research was to determine the effect of two tillage practices (namely, moldboard plowing and no-till) and two fertilizer management practices (single and three N applications, with the three applications at a lower total rate) on the residual soil profile NO_3-N and corn yield.

Materials and Methods

Experimental Design

A field study was conducted from 1984 to 1991 at the Iowa State University Agronomy and Agricultural Engineering Research Center near Ames, Iowa. Soils at the experimental site are from the Canisteo-Clarion-Nicollet association formed under glacial till and are characterized by gentle rolling surface moraine with an average slope less than 3%. Surface drainage is poorly developed due to the undulating surface. Subsurface drainage is related to soil type (Canisteo soils are poorly drained, Clarion soils are well-drained, and Nicollet soils are somewhat poorly drained), and permeability is moderate. Selected soil properties at the experimental site are given in Kanwar et al. (1988).

Six plots, each drained with a single subsurface drain at a depth of 122 cm, were sampled for residual soil NO_3-N beginning in 1984. This experimental area was planted to oats during the 1983 growing season. Table 1 gives the dates of planting, harvesting, and N application and plant populations (corn variety Pioneer No. 3475). Plant populations are an average of five measurements per plot.

Experimental Variables

Two replications of two tillage systems (no-till and conventional) and one N management practice (single application of 175 kg/ha) were used for continuous corn production requiring four of the six plots. The conventionally tilled plots were moldboard plowed each fall. The remaining two plots were also cropped to corn using no-tillage, but three N applications totaling 125 kg/ha were made. The first application of 25 kg/ha was made shortly after planting, a second application of 50 kg/ha was made in June, and the third application of 50 kg/ha was applied in late June or early July (table 1). The decision to reduce the total application by 50 kg/ha was made to determine if the potential of improved timing with three applications could overcome this reduction relative to corn yield. The recommended N rate for continuous corn on these soils would be 196 kg/ha. The N was point-injected to a depth of 10 cm (Baker et al., 1989) in liquid form (containing 28% N as urea/ammonium nitrate).

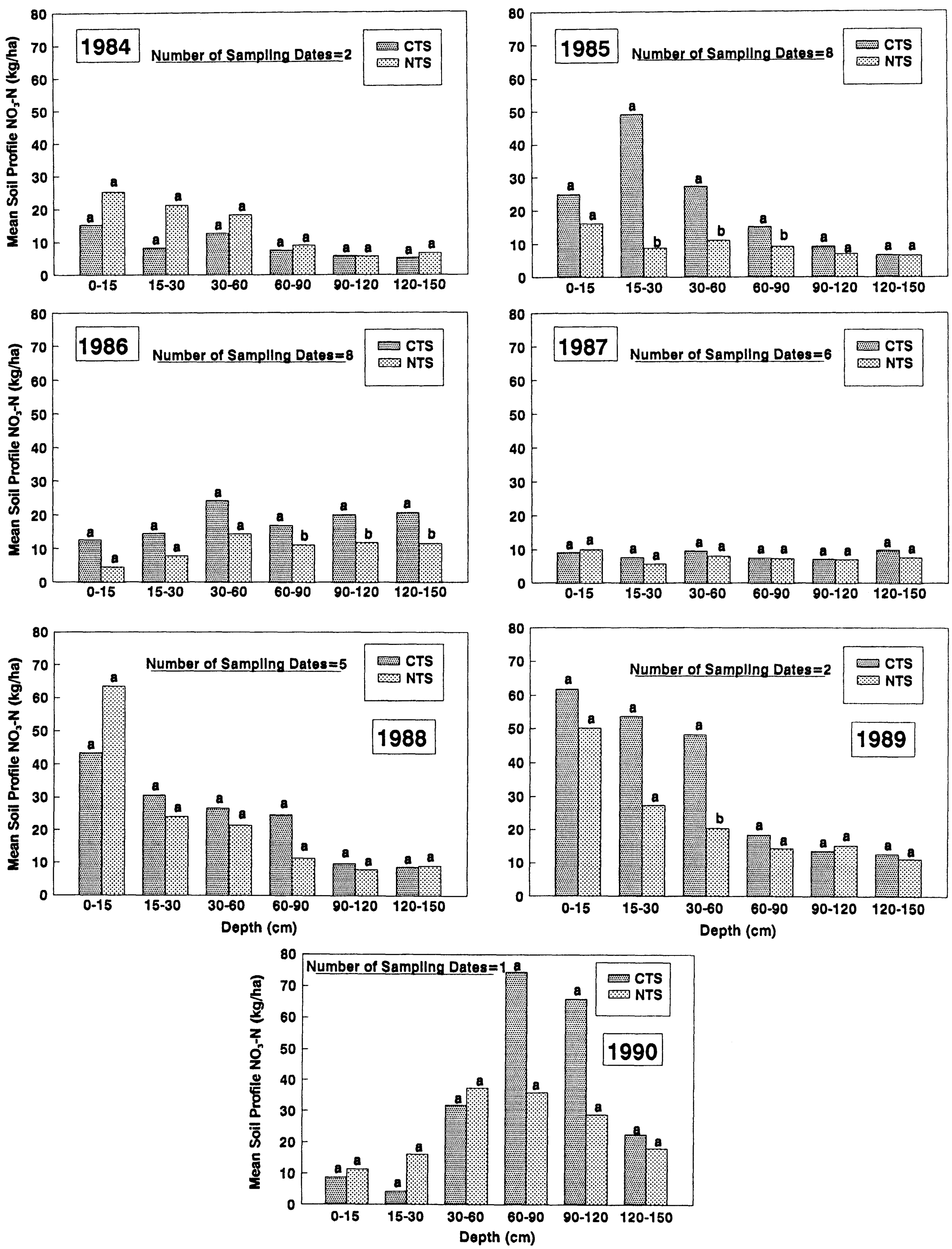

Figure 2–Tillage effects on the average soil NO_3-N amounts as a function of depth for various years (means with the same letter represent no significant difference; CTS = conv. tillage single; NTS = no-till single).

Sampling Procedure

A 3.2-cm-diameter × 45.7-cm-long soil probe with an open faced style sampling tube was used to collect soil samples from the field sites. Samples were taken to a depth of 150 cm at three locations within a plot, one along and two on either side of the tile line, one-fourth the distance (9 m) between the tile lines and 30 m from the bottom plot boundary. For the top 30 cm, two samples were taken in 15-cm increments; samples were then taken to 150 cm in 30-cm increments. Samples were placed into prelabeled 1-L freeze bags and sealed. The probe was cleaned after each sampling before proceeding to the next depth. The bagged soil samples were stored in large coolers in the field to limit loss of moisture and N during transport to the laboratory for moisture and NO_3-N analysis. The soil samples were then stored for no more than 60 d at 1° C until extractions were completed.

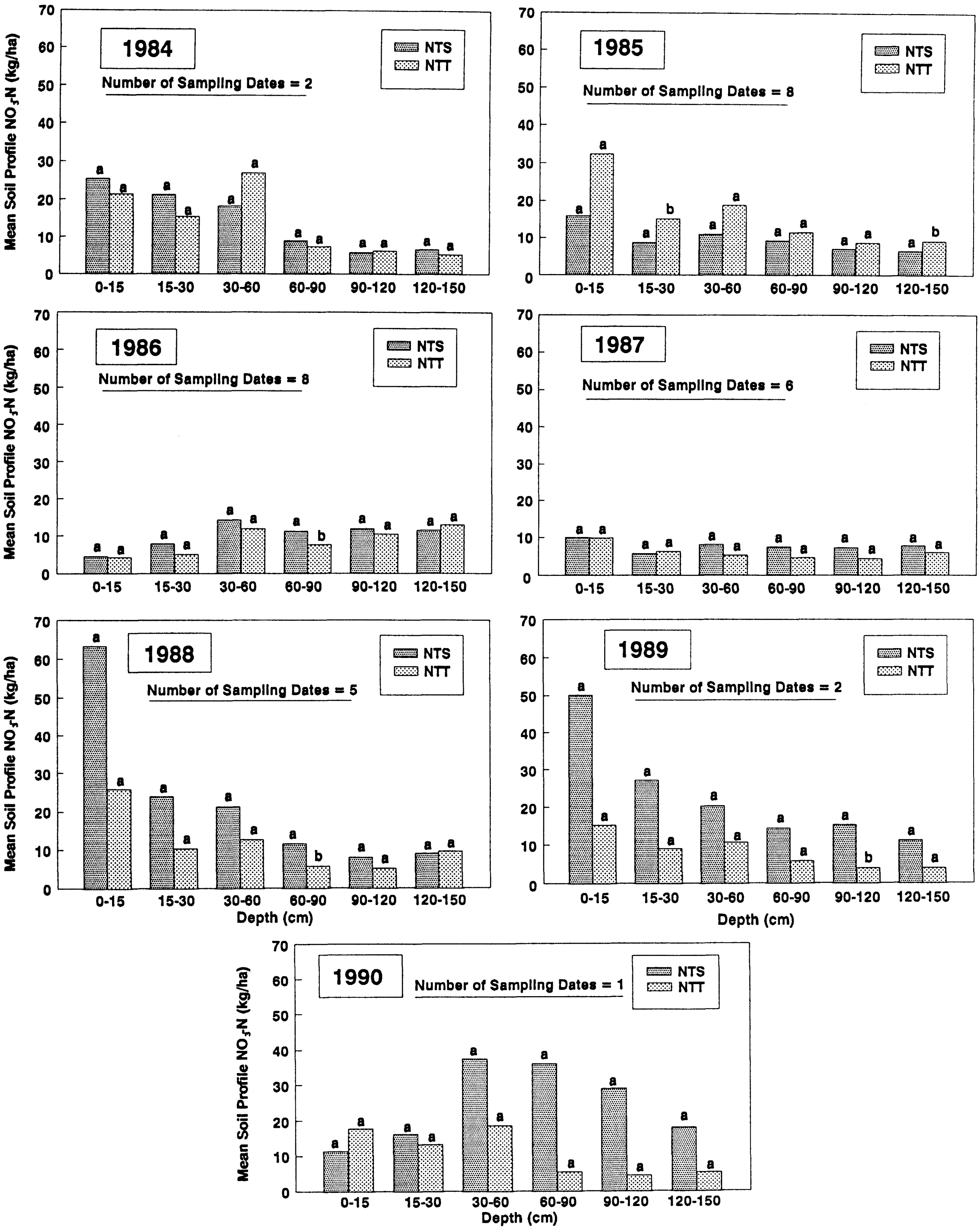

Figure 3–Effect of N management on soil NO_3-N amounts by depth (means with the same letter represent no significant difference; NTS = no-till single; NTT = no-till three).

Sample Analysis

A 2-N potassium chloride extraction solution was used to extract NO_3-N from soil samples (Keeney and Nelson, 1982). Soil moisture was determined gravimetrically. Soil solution extracts were analyzed for NO_3-N by the cadmium-reduction method using a Technicon Analyzer II system (Kanwar et al., 1988).

Statistical Analysis

Statistical analyses of the NO_3-N amounts in the soil profile at each depth and with time were performed to determine significant differences in means by using the analysis of variance procedure (ANOVA) with SAS (SAS Institute, 1985). All analyses were performed at the 95% probability level. Analyses were broken into two parts:

- Conventional tillage versus no-till at the same rate of N application (175 kg/ha) to evaluate the effect of tillage on soil profile residual NO_3-N.

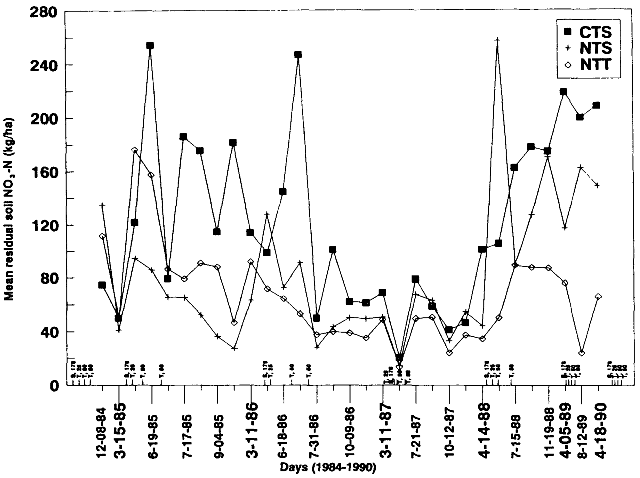

Figure 4–Mean residual soil NO_3-N amounts as a function of time during the growing season from 1984 to 1990 (S = single application of 175 kg-N / ha; T = three split applications of 25, 50, and 50 kg-N ha). The abscissa positions indicate the timing of N application.

- Single versus three applications of N fertilizer for the no-till system to evaluate the effect of N management on residual NO_3-N in the soil profile.

Furthermore, the data were analyzed by depth for each sampling date and location and between years. Comparisons were not made from one growing season to the other, due to the lack of a uniform and balanced data set and large differences in rainfall during the growing seasons. Regression analysis of the data was done to obtain a trend of residual NO_3-N variation in the soil profile with depth.

Results and Discussion

Figure 1 shows the annual precipitation at the experimental site for the eight-year study period; the long-term average is 81 cm. Figure 2 shows the effect of tillage on average soil NO_3-N amounts as a function of depth. The amounts of NO_3-N present in the soil profile for 1984, the beginning year of the study, were similar at each depth for the two tillage systems, but show a decreasing trend as a function of depth. At the time of harvesting in 1984, there was more NO_3-N in the soil profile of no-till plots compared to conventional tillage plots. In 1985, for each depth segment, conventional tillage plots had higher amounts of NO_3-N than no-till plots with the differences significant for the middle layers. Large amounts of NO_3-N accumulated in the 15- to 30-cm layer in 1985, a dry year. Relatively higher NO_3-N amounts were observed in deeper soil layers of the conventionally tilled plots in 1986, a wet year. The amounts of NO_3-N were statistically different between tillage systems at the three deeper soil depths. The increase in NO_3-N levels in 1986 under conventional tillage, as shown in figure 2 might be due to increased mineralization of N and some left-over N from 1985. In 1987, also a wet year, the NO_3-N levels in the soil profile were further reduced, possibly due to leaching and/or denitrification. Precipitation received that year was sufficient to flush some of the accumulated amounts of

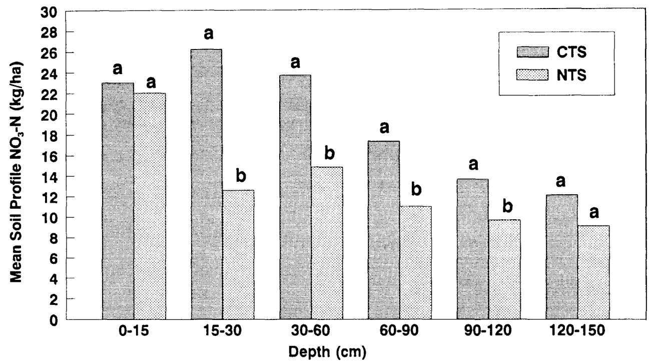

Figure 5–Overall effect of tillage on soil NO_3-N amounts by depth when a single application of 175 kg N / ha was applied (means with different letters represent significant difference; CTS = conv. till single; NTS = no-till single).

NO_3-N to the deeper soil layers. During 1985, 1988, and 1989, all three dry years, the NO_3-N levels were higher in the near surface layer whereas in 1986 and 1987, two wet years, much of the NO_3-N in the soil profile was leached (Kanwar et al., 1988). Considering all the data on soil NO_3-N, no-till was found to be better from water quality point of view; it has less NO_3-N in the profile and equivalent corn yields. In 1990, an extremely wet year, only one set of early spring soil samples could be collected.

Figure 3 shows the effect of different N management techniques on soil residual NO_3-N. In 1984, three-application plots generally had lower NO_3-N levels in the soil profile than the single higher-rate application, but statistically there were no differences (these values represent only two sampling times, before planting and after harvesting). In 1985, a dry year, the trend changed. Three applications had more NO_3-N in the soil profile than the single application. In 1986, the expected trend of lower NO_3-N levels in some layers of the soil profile for three applications was observed, and NO_3-N from the upper soil profile moved down to the tile drain depth due to significant amount of rainfall. In 1987, again a relatively wet year, concentrations remained low apparently because most of the NO_3-N was either leached out of the root zone or denitrified as also occurred in the conventional tillage plots which received a single application of N (fig. 2). A considerable difference in NO_3-N amounts was observed in 1988, a dry year. More NO_3-N accumulated in the upper 15 cm and gradually decreased with depth. No-till plots receiving three applications of N resulted in considerably less NO_3-N than the single higher rate of N application. The data in figure 4 for 1988 show an increasing trend with time possibly due to greater mineralization, although the increase is less for the three application plots. Similar trends were observed in 1989. Due to the smaller number of observations in 1989 and 1990, the least significant difference obtained was higher for some years and at certain depths.

Figure 4 shows the average total residual NO_3-N distribution in the soil profile under all tillage treatments for the fall and corresponding spring seasons at their respective sampling dates. This figure shows that the no-till system resulted in less residual NO_3-N in the soil profile than conventional tillage. Also, the NO_3-N levels were much lower in wet years of 1986 and 1987 possibly

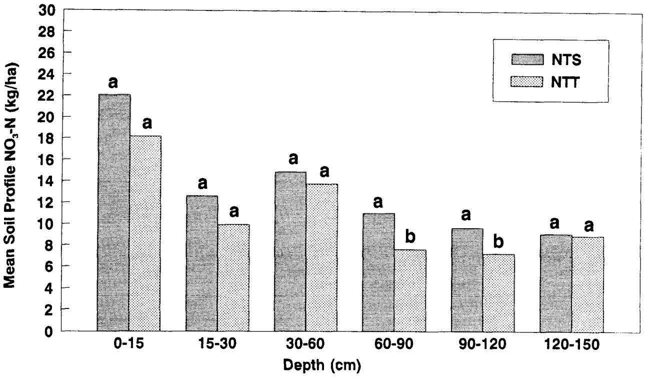

Figure 6–Overall effect of N management on soil NO_3-N amounts by depth under no-till system (means with different letters represent significant difference; NTS = no-till single; NTT = no-till three).

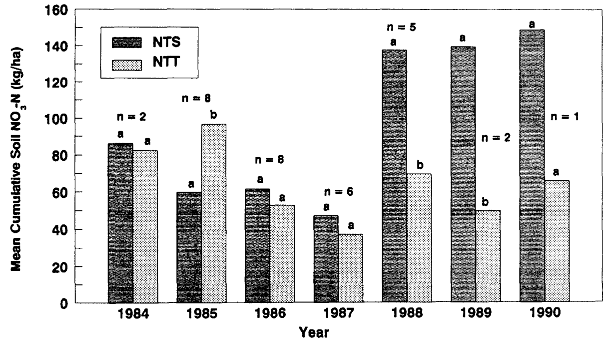

Figure 8–Effect of single vs. three N applications on annual average cumulative NO_3-N under no-till system (NTS = no-till single; NTT = no-till three).

indicating the effects of denitrification and/or increased leaching of NO_3-N to groundwater.

Figures 5 and 6 show the overall effects of tillage treatments and N management on NO_3-N contents in the soil profile. These figures show the mean NO_3-N amounts for each depth for all years. Significant differences in the NO_3-N amounts were observed at several depths in the soil profile. Under conventional tillage, more NO_3-N accumulated in the upper soil layers where most of the macropores were destroyed due to tillage activity, while the soil structure below the 60-cm depth remains undisturbed. In the no-till system, where macropores are allowed to develop and persist, the structure at the soil surface could be markedly different, but may be similar to that in conventional tillage at greater depths. The no-till system under both N management practices indicates significantly lower NO_3-N amounts in parts of the soil profile with the lower rate, three application treatment, with nearly constant values at the depth near the tile drain.

Figures 7 and 8 show the cumulative amounts of NO_3-N in the soil profile for the three treatments for all years. Cumulative soil NO_3-N amounts (profile totals of all five depths in kg/ha) were used to evaluate the effect of tillage and N management practice on soil NO_3-N. Figure 7 compares the tillage treatments at the single N application rate of 175 kg/ha. Except for the first year, 1984, no-till resulted in, on the average, less residual NO_3-N in the profile than conventional tillage. In years where fewer soil samples could be collected, 1984, 1989, and 1990, the least significant difference values were considerably higher than for years 1985, 1986, 1987, and 1988 where at least five sets of soil samples were collected. The NO_3-N trend was markedly influenced by climatic conditions for all the tillage treatments. In wet years (1986 or 1987) lower amounts of NO_3-N were observed in the soil profile under all the three treatments indicating increased leaching to groundwater and/or denitrification. Also, higher corn yields of 1986 and 1987 suggest increased N uptake by the plants leaving less NO_3-N in the soil profile.

Figure 9 shows the quadratic regression models giving NO_3-N levels in the soil profile as a function of depth for the three N management/tillage treatments. Regression equations and their R^2 values are also shown. The observed cumulative NO_3-N amounts in conventional tillage single, no-till single and no-till three were 116.4, 79.6, and 65.9 kg/ha, respectively. These results indicate that conventional tillage single and no-till single treatments have more NO_3-N than no-till three treatment, throughout the profile which accounts for low risk of potential groundwater contamination. The results are in accordance with the reported findings of Kanwar et al. (1988).

Figure 10 shows average corn yields as a function of tillage and N-fertilizer application rate (single application

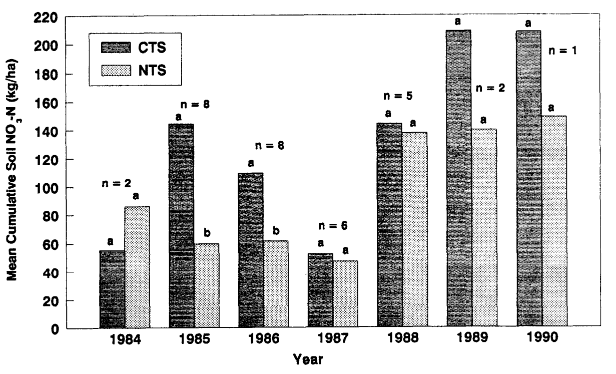

Figure 7–Annual average cumulative NO_3-N amounts in the soil profile as a function of tillage and year (means with the same letter represent no significant difference; n = no. of samplings / yr; CTS = conv. tillage single; NTS = no-till single).

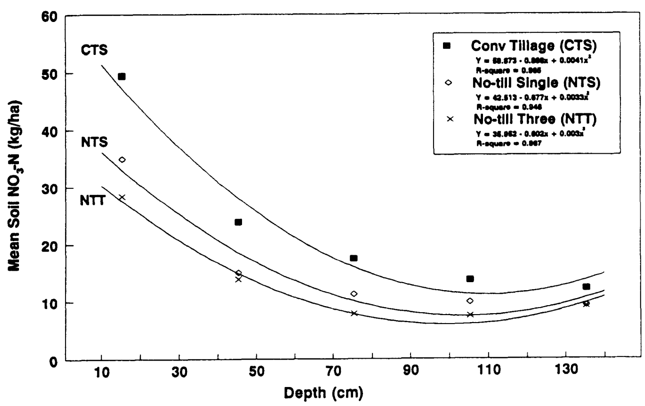

Figure 9–Regression models predicting the average NO_3-N levels in the soil profile as a function of depth, tillage, and method of N application.

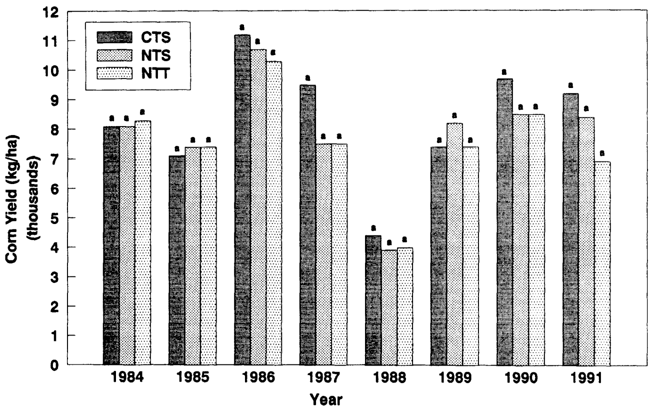

Figure 10–Comparison of corn yield under the two tillage treatments.

of 175 kg/ha and three applications totaling 125 kg/ha). Statistically, no significant differences were found either between tillage or between N management practices. This figure also shows that higher corn yields were obtained in wet years of 1986, 1987, 1990, and 1991. Yields peaked near 11.2 Mg/ha in 1986, 9.5 Mg/ha in 1987 and 9.7 Mg/ha in 1990. However, yields were considerably reduced in 1988 due to extremely dry conditions resulting in higher amounts of NO_3-N remaining in the soil profile. The yield for three applications, however, was equal to that obtained from the single application.

Summary and Conclusions

A field study was conducted to determine the effects of tillage and N management practices on the residual NO_3-N in the soil profile. This study supports the following conclusions:

- No-till with three split N applications totaling 125 kg/ha resulted in lower amounts of residual NO_3-N in the soil profile in comparison to a single N application of 175 kg/ha. Corn yields obtained from three split applications were not significantly different from the single higher N application rate under either tillage system. This result indicates that farmers can sometimes apply less N fertilizer without reducing corn yields with possible benefits of reducing the potential for NO_3-N leaching to groundwater.
- Under conventional tillage system, more residual N accumulated in the top 60 cm of the soil profile than under no-till system. This possibly was due to higher rates of mineralization and less leaching to the groundwater.

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